Adaptive power system stabilizer for optimum damping of active power swings

To mitigate the risk of instability in distribution networks caused by power systems being operated closer to their limits, utilities are demanding more effective damping of the active power oscillations occurring after grid disturbances. Conventional power system stabilizers allow optimum stability only at a defined operating point, and the results are less than an optimum when the system parameters vary. ABB and the University of Calgary, Canada, have developed an adaptive power system stabilizer (APSS) which, by adjusting continually to changing network and operating conditions, ensures optimum damping of active power oscillations at all times. Tests carried out on simulators and actual machines have demonstrated the damping properties of the APSS in an impressive way.

The deregulation of the European energy markets is leading to power systems often being operated close to their limits, thereby increasing the risk of instability in the distribution networks. One outcome of this is that the power utilities are making greater demands on the voltage regulation of synchronous generators. In particular, there is a strong call for more effective damping of the active power oscillations occurring after disturbances in the electrical grid. Power system stabilizers embedded in the electronic excitation equipment of synchronous generators improve active power stability, but optimum results are obtained only at a particular operating point. What is more, the results are less than optimum when the system parameters, ie the operating points of the generator or the network conditions, vary. To take account of changing system parameters the stabilizing equipment has to be adaptive.

PSS versus APSS

The parallel operation of power plants or groups of plants raises fundamental questions about the dynamic behaviour and stability of the synchronous machines. Disturbances in the electrical grid, for example, cause oscillation of the active power produced by the generators, which has to be damped as quickly as possible. The damping properties depend on different parameters, eg the characteristic values of the synchronous machine, the power system impedances and the operating point of the generator. It is common practice to improve the damping properties by means of a stabilizer which acts on the voltage regulating function of the generator exciter.

A conventional power system stabilizer (PSS) makes use of the deterministic regulation theory, ie a linearized model is used to obtain optimum results for a specific operating point. A look at the change in active power in a real-world generator network configuration, however, shows that there are significant non-linear relationships that have to be taken into account in the modelling. A conventional PSS is not able to fulfil this condition. A new-generation power system stabilizer with adaptive capability is therefore needed. This capability must include the following features:

- Ability to identify the operating point of the generator and the network impedance.
- Adjustable PSS parameters to take account of the continuous variation in system parameters.
- Adjustable transfer function for a wide frequency range (eg, a subsynchronous swing in power output when two machines are connected in parallel).

The flexibility and simple design of self-adjusting regulators based on microprocessor technology make them one of the most effective adaptive regulation devices on the market, and especially suitable for power system stabilization in connection with synchronous machines.

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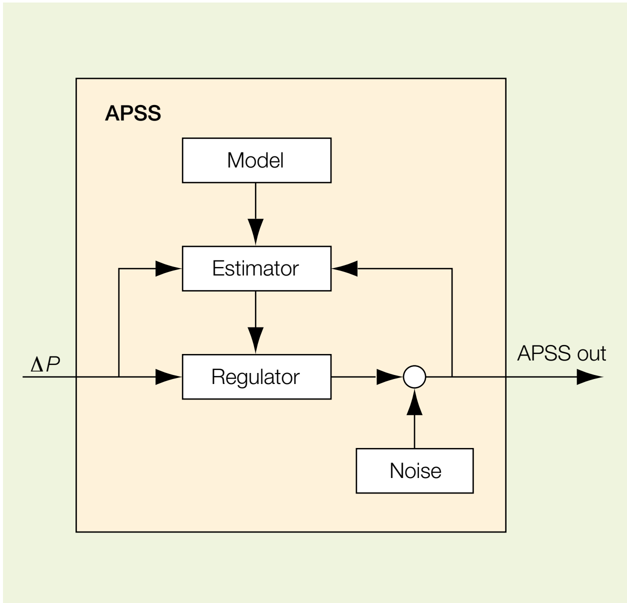
The APSS algorithm runs on a drawout module which can be simply inserted in an existing voltage regulator rack. No settings or additional wiring are necessary. **1**

Block diagram of the adaptive power system stabilizer (APSS) **2**

ΔP Change in power output



Recognizing this, ABB and the University of Calgary in Canada jointly developed an adaptive stabilizer with all the capabilities discussed above **1**. The ABB hardware on which the software runs is used among other things to regulate the generator voltage in excitation systems.

Principle of operation of the APSS

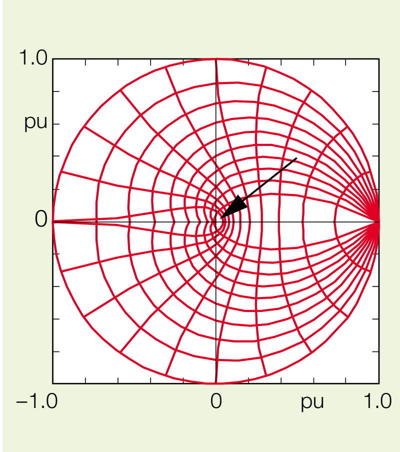
The principle of adaptive power system stabilization can be explained by considering a system which has stochastic characteristics and is subject to non-predictable interference. The regulator input signal normally represents observations of certain system variables. Due to the stochastic interference, eg unexpected changes in load, noise, etc, such observations are not representative. Furthermore, the regulation strategy has to be based on momentary recognition of the system dynamics and past values of input and output variables. For it to have this capability an adaptive stabilizer requires three different function groups – the system model, estimator and regulator **2**.

System model

The system model works in conjunction with the estimator and regulator to determine the system parameters of the actual system. In a complex, non-linear system, the system parameter vector is unknown and time-dependent. Such a system can be modelled by means of a low-order linear system with time-variable parameters. A system of at least the 9th order is generally needed to accurately describe the parameters of an actual system. However, it can be shown that an adequately good approximation is also achieved with a 3rd-order system. This simplification is necessary as the calculation of a 9th-order system would take up too much computing time.

Estimator

The estimator continually attempts to find model system parameters with characteristics which are as close as possible to those of the real-world system. The output signal of the model is compared with the output signal of the real system (ΔP) in order to evaluate the error. If a deviation is found, the model parameters are adjusted by means of a special algorithm. However, correct identification of the system parameters is only possible when the active power varies continuously. To achieve this condition during steady-state operation of the generator a weak stochastic signal (noise) is added to the stabilizer output.



Shift of poles in the complex Z-plane **3**

Red lines *Constant damping*
Arrow *Increasing damping*

Regulator

The regulator performs calculations in parallel with the continuous identification of the system parameters, the result forming the output signal of the APSS. The regulator, which is supplied continuously with values formed by the estimator, now attempts to generate the regulator signal required for optimum damping. This is achieved, in accordance with the well-known regulator theory, by shifting the poles of the closed loop as close as possible to the zero point in the Z-axis **3**.

The APSS output signal subsequently passes to the input (mixing point) of the automatic voltage regulator **4**. The only input signal required by the APSS is the value of the power used to accelerate the rotor. This value is the difference ΔP between the electrical output P_{el} and the mechanical power input P_m. ΔP is expressed in per-unit values, at nominal speed, as follows:

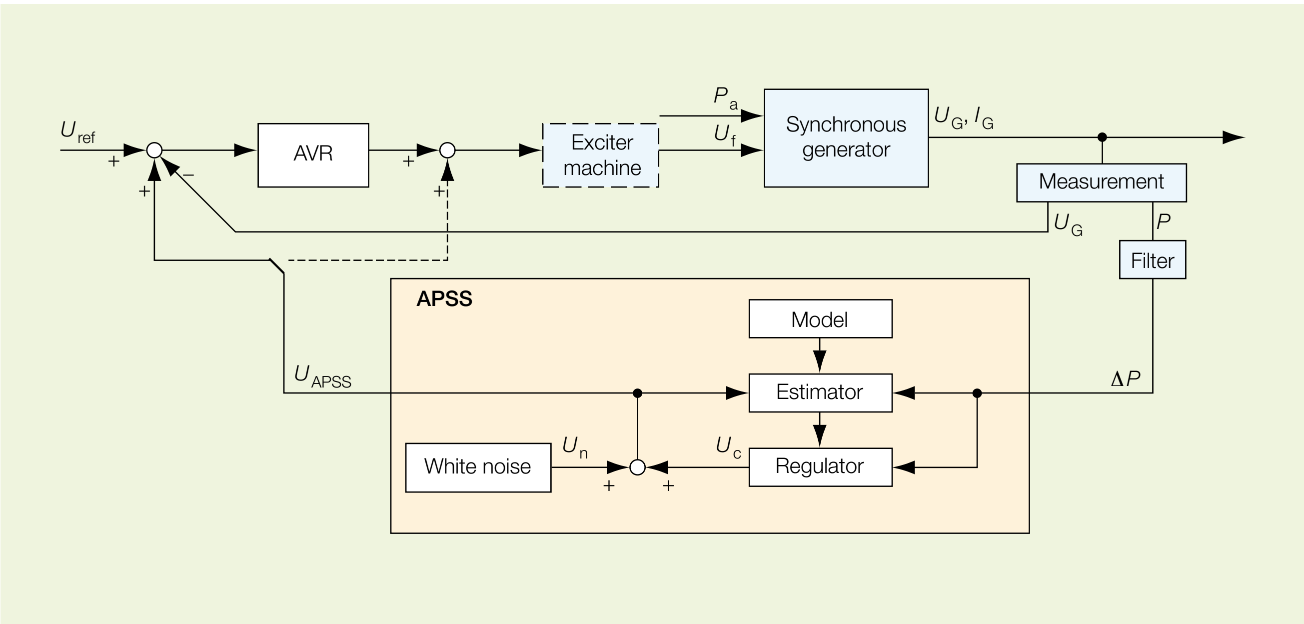
$$\Delta P = 2H\frac{d\omega}{dt} = P_{el} - P_m$$

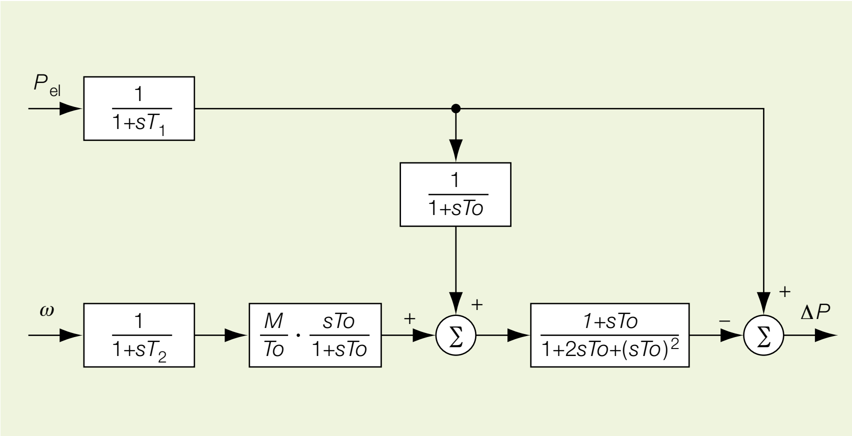
Interaction of the adaptive power system stabilizer (APSS) and automatic voltage regulator (AVR) in the closed-loop circuit of an excitation system **4**

I_G *Generator current*
P *Generator output power*
P_a *Turbine drive power*
ΔP *Acceleration power*

U_{APSS} *Stabilizer signal*
U_C *AVR control signal*
U_f *Rotor field voltage*
U_G *Generator voltage*

U_n *Noise signal*
U_{ref} *AVR setpoint*





Transfer function used to obtain the acceleration power ΔP **5**

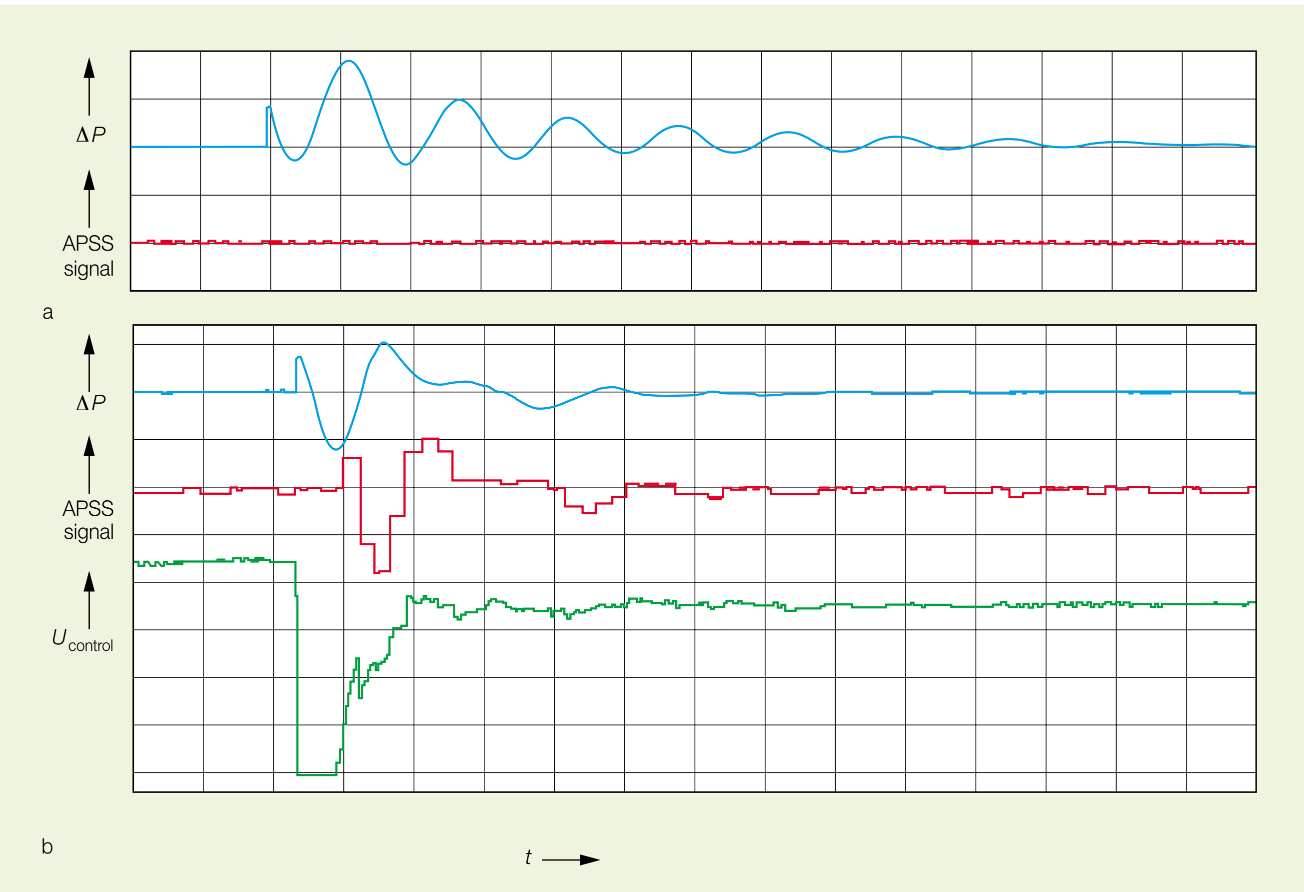
P_{el}	*Electrical output*
ω	*Angular frequency of rotor*
M	*Machine constant*
s	*Laplace variable*
To	*Time constant of turbine-generator set*
T_1, T_2	*Measuring filter time constants*

where H is the inertia of the machine and ω is the angular frequency of the rotor.

The electrical output P_{el} is determined by measuring the electrical system variables of the generator, eg voltages and currents. Often, it is not possible to measure the mechanical power input P_m of the synchronous machine direct. However, the mechanical driving power can be reconstructed from the measured frequency and the mechanical model of the mass inertia of the turbine and generator. **5** shows the transfer function used to determine the acceleration power used as the input signal for the adaptive slip stabilization. No other system values are required to calculate

Active power swings following a jump in reactive power, (a) without and (b) with APSS. Results of tests carried out on a 45-MVA salient-pole generator. **6**

APSS signal	*APSS output signal (50 mV/div)*	$U_{control}$	*Regulator voltage (2 V/div)*
ΔP	*Change in power (0.1 pu/div)*	t	*Time (500 ms/div)*



the output signal, since the estimator and the regulator use the algorithm to find the optimum output signal for the best possible damping of the oscillations.

APSS hardware

Since matrix calculations are used extensively by the APSS, the algorithm used by the APSS has been written in MODULA-2. The software currently runs on the universal processor PM A324 of the PSR high-speed programmable controller. PSR hardware is used widely by ABB, eg in the control electronics of UNITROL® P excitation systems. The device can be simply plugged into any unused slot in the UNITROL® P system. No additional wiring is necessary as the data communication takes place entirely over the internal parallel data bus B448.

APSS software

The APSS algorithm is loaded into an EPROM, which is plugged into the space provided in the PM A324 processor. The APSS can be integrated in the existing software of the UNITROL® P voltage regulator simply by implementing an additional FUPLA program section. (FUPLA is a programming tool used to program the software in the UNITROL® P system.)

Testing the APSS

The functionality of the APSS was tested in the field on a 45-MVA salient-pole generator installed at Feistritz power station in Austria, and on a 100-MVA solid-pole machine installed at Mainz, Germany. In addition to these field tests, numerous other tests were carried out on a generator simulator. The correct functioning of the APSS was confirmed on both the generator model and the installed machines. **6** shows the swing in active power following a jump in reactive power with and without the APSS at Feistritz.

Advantages of APSS over conventional stabilizers

With adaptive power system stabilizers there is no need to calculate the parameter settings, as is the case with conventional stabilizing equipment. This is an important advantage since the calculations are often difficult and unreliable, due mainly to the power system parameters not being known. As a result, the settings are determined using empirical methods that apply only to the grid conditions prevailing at a certain moment in time.

The settings calculated by conventional system stabilizers are not always an optimum or even valid under all operating conditions. With adaptive stabilizers the system parameters adjust automatically to changing grid conditions, making such settings unnecessary.

APSS applications

The APSS can be used with every type and size of generator. In order to fully utilize its capabilities, it should preferably be used where grid conditions are complex and unpredictable. The APSS is especially well suited for use in networks with the following characteristics:

- Unstable power systems with high short-circuit impedances
- Power systems subjected to strong load fluctuations
- Power systems operated as isolated networks
- Systems with long feeder lines from the power plants to the distribution centers

Each of the above power systems is characterized by constantly changing or high system impedances. The adaptive power system stabilizer provides the required stability in every case.

References

[1] C. C. Hang, T. H. Lee, W. K. Ho: Adaptive control. Instrument Society of America, 1993.

[2] Y. S Chow, S. J. Cheng, O. P. Malik, G. S. Hope: An adaptive power system stabiliser. IFAC Symposium, 1986.

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